Safety First!

Part 1 — Station Power.

***This article is the first of a multipart series on safety, excerpted from the* 2017 ARRL Handbook.**

The standard power available from commercial mains in the United States for residential service is 120/240 V ac. The "primary" voltages that feed transformers in our neighborhoods may range from 1300 to more than 10,000 V. Generally, the responsibility for maintaining the power distribution system belongs to a utility company, electric cooperative, or city. The "ownership" of conductors usually transfers from the electric utility supplier to the homeowner, where the power connects to the meter or weather head. If you are unsure of where the division of responsibility falls in your community, a call to your electrical utility will provide the answer. Figure 1 shows the typical division of responsibility between the utility company and the homeowner. This article is concerned more with wiring practices in the shack, as opposed to within the equipment in the shack.

Station Concerns

There never seem to be enough power outlets in your shack. A good solution for small-scale power distribution is a switched power strip with multiple outlets. The strip should be listed by a nationally recognized testing laboratory (NRTL) such as Underwriters Laboratories, (UL), and should incorporate a circuit breaker. See the sidebars, "What Does a UL Listing Mean?" and "How Safe are Outlet Strips?" for warnings about poor quality products. It is poor practice to "daisy-chain" several power strips, and it may actually be a code violation. If you need more outlets than are available on a strip, have additional wall outlets installed.

Whether you add new outlets or use power strips, be sure not to overload the circuit. National and local codes set permissible branch capacities according to a rather complex process. Here's a safe rule of thumb: consider adding a new circuit if the total load is more than 80% of the circuit breaker or fuse rating. (This assumes that the fuse or breaker is correct. If you have any doubts, have an electrician check it.)

Do-It-Yourself Wiring

Amateurs sometimes "rewire" parts of their homes to accommodate their hobby. Most local codes *do* allow for modification of wiring (by building owners), so long as the elec-

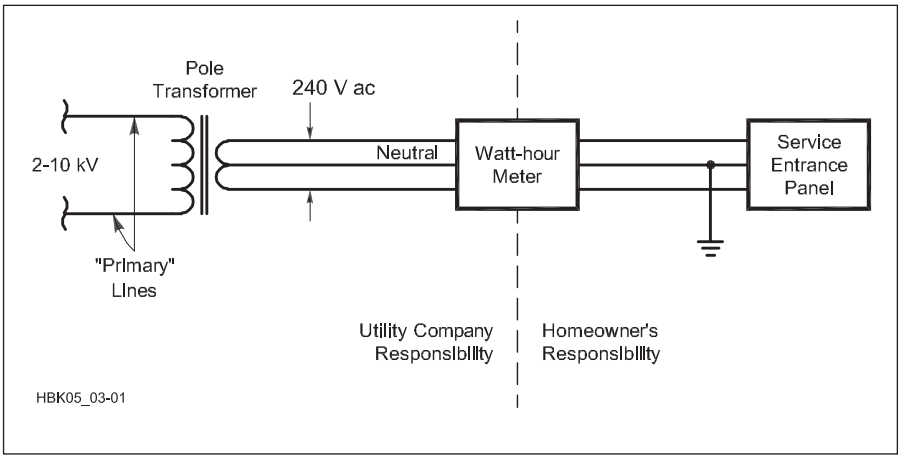


Figure 1 — Typical division of responsibility for maintenance of electrical power conductors and equipment. The meter is supplied by the utility company.

What Does a UL Listing Mean?

Underwriters Laboratories (UL) is one of several nationally recognized testing laboratories (NRTLs), and probably the most well known. A UL listing *does not* mean what most consumers expect it to mean! More often than not, the listing *does not* relate to the performance of the listed product. The listing simply indicates that a sample of the device meets certain manufacturers' construction criteria. Similar devices from the same or different manufacturers may differ significantly in overall construction and performance, even though all are investigated and listed against the same UL product category. There is also a difference between a listed device and a listed component.

Many local laws and regulations, as well as the NEC, require that equipment and components used in electrical installations be listed by a NRTL. Some jurisdictions (Los Angeles County) require that any electrical equipment sold to consumers be listed.

The consumer must also be aware of the fine distinctions in advertising between a device or component that is advertised as "listed" or "designed to meet" or "meets." The latter two may not actually have been tested, or if tested, may have been tested by the manufacturer, and not an independent body.

It's also important to know that in some cases UL (and other standards organizations) only publish a standardized test procedure, but don't necessarily list or test the devices. Many standards also define varying levels of compliance, so knowing that your device meets some part of the standard may not be enough to know whether it meets *your* particular needs.

trical codes are met. Before making changes to your wiring, it would be wise to determine what rules apply and what agency has the authority to enforce them. This is called the *authority having jurisdiction* (AHJ) and it varies from location to location.

Generally, the building owner must obtain an electrical permit before beginning changes or additions to permanent wiring. Some jobs may require drawings of planned work. Often the permit fee pays for an inspector to review the work. Considering the risk of injury or fire if critical mistakes are left uncorrected, a permit and inspection are well worth the effort. *Don't take chances* — seek assistance from the building officials or an experienced electrician if you have *any* questions or doubts about proper wiring techniques.

Ordinary 120 V circuits are the most common source of fatal electrical accidents. Line voltage wiring must use an approved cable, be properly installed according to the electrical code. Remember that high-current, low-voltage power sources, such as car batteries and high-current power supplies, can be just as dangerous as high-voltage sources, from melting metal, sparks, and short circuits.

Never work on electrical wiring with the conductors energized! Switch off the circuit breaker or remove the fuse and take positive steps to ensure that others do not restore the power while you are working, such as using a circuit-breaker lockout. (Figure 2 illustrates one way to ensure that power will be off until you want it turned on.) Check the circuit with an ac voltmeter to be sure that it is "dead" *each time you begin work*.

Before restoring power, check the wiring with an ohmmeter. From the installed outlet, there should be good continuity between the neutral conductor (white wire, "silver" screw) and the grounding conductor (green or bare wire, green screw). An ohmmeter should indicate a closed circuit between the conductors. (In the power line, high-voltage world, line workers apply a shorting jumper before starting work so if the power does get reapplied, the safety jumper takes the hit.)

There should be no continuity between the hot conductor (black wire, "brass" screw) and the grounding conductor or the neutral conductor. With all other loads removed from the circuit (by turning off or unplugging them), an ohmmeter should indicate an *open* circuit between the hot wire and either of the other two conductors.

Commercially available plug-in testers are a convenient way to test regular three-wire receptacles, but can't distinguish between the neutral and ground being reversed.

National Electrical Code (NEC)

Fortunately, much has been learned about how to harness electrical energy safely. This collective experience has been codified into the *National Electrical Code*, or NEC, simply known as "the code." The code details safety requirements for many kinds of electrical installations. Compliance with the NEC provides an installation that is *essen-*

How Safe Are Outlet Strips?

The switch in outlet strips is generally *not* rated for repetitive *load break* duty. Early failure and fire hazard may result from using these devices to switch loads. Misapplications are common (another bit of bad technique that has evolved from the use of personal computers), and manufacturers are all too willing to accommodate the market with marginal products that are "cheap."

Nonindicating and poorly designed surge protection also add to the safety hazard of using power strips. MOVs with too low a threshold voltage often fail in a manner that could cause a fire hazard, especially in outlet strips that have nonmetallic enclosures, because day-to-day voltage surges that are otherwise unexceptional degrade the MOV each time, until it fails shorted.

A lockable disconnect switch or circuit breaker is a better and safer station master switch.

About the National Electrical Code

Exactly how does the National Electrical Code become a requirement? How is it enforced?

Cities and other political subdivisions have the responsibility to act for the public safety and welfare. To address safety and fire hazards in buildings, regulations are adopted by local laws and ordinances usually including some form of permit and accompanying inspections. Because the technology for the development of general construction, mechanical and electrical codes is beyond most city building departments, model codes are incorporated by reference. There are several general building code models used in the US: Uniform, BOCA, and Southern Building Codes are those most commonly adopted. For electrical issues, the *National Electrical Code* is in effect in virtually every community. City building officials will serve as "the authority having jurisdiction" (AHJ) and interpret the provisions of the Code as they apply it to specific cases.

Building codes differ from planning or zoning regulations: Building codes are directed only at safety, fire, and health issues. Zoning regulations often are aimed at preservation of property values and aesthetics.

The NEC is part of a series of reference codes published by the National Fire Protection Association, a nonprofit organization. Published codes are regularly kept up to date and are developed by a series of technical committees whose makeup represents a wide consensus of opinion. The NEC is updated every 3 years. It's important to know which version of the Code your local jurisdiction uses, since it's not unusual to have the city require compliance to an older version of the Code. Fortunately, the NEC is usually backward compatible: that is, if you're compliant to the 2008 Code, you're probably also compliant to the 1999 Code.

Do I have to update my electrical wiring as code requirements are updated or changed?

Generally, no. Codes are typically applied for new construction and for renovating existing structures. Room additions, for example, might not directly trigger upgrades in the existing service panel unless the panel was determined to be inadequate. However, the wiring of the new addition would be expected to meet current codes. Prudent homeowners, however, may want to add safety features for their own value. Many homeowners, for example, have added GFCI protection to bathroom and outdoor convenience outlets.

Figure 2 — If the switch box feeding power to your shack is equipped with a lock-out hole, use it. With a lock through the hole on the box, the power cannot be accidentally turned back on. [Photo courtesy of American ED-CO]

tially free from hazard, but not necessarily efficient, convenient, or adequate for good service (paraphrased from NEC Article 90-1a and b). While the NEC is national in nature and sees wide application, it is not universal.

Local building authorities set the codes for their area of jurisdiction. They often incorporate the NEC in some form, while considering local issues. For example, Washington State specifically exempts telephone, radio, and television wires and equipment from conformance to electrical codes, rules and regulations. However, some local jurisdictions (city, county, and so on) do impose a higher level of installation criteria, including some of the requirements exempted by the state.

Code interpretation is a complex subject, and untrained individuals should steer clear of the NEC itself. The NEC is not written to be understood by do-it-yourselfers, and one typically has to look in several places to find *all* the requirements. (For instance, Articles 810, 250, *and* 100 all contain things applicable to typical Amateur Radio installations.) Therefore, the best sources of information about code compliance and acceptable practices are local building officials, engineers, and practicing electricians.

The Internet has a lot of information about electrical safety, the electrical code, and wiring practices, but you need to be careful to make sure the information you are using is current and not out of date. The ARRL Volunteer Consulting Engineer (VCE) program can help you find a professional who understands the amateur radio world, as well as the regulatory environment. There are also a variety of websites with useful information (such as **www.mikeholt.com**), but be aware that advice may be specific to a particular installation or jurisdiction and not applicable for yours. With that said, let's look at a few NEC requirements for radio installations.

Homebrew and "The Code"

In many cases, there are now legal requirements that electrical equipment have been listed by an NRTL, such as Underwriters Laboratories. This raises an issue for hams and homebrew gear, since it's unlikely you would take your latest project down to a test lab and pay them to evaluate it for safety.

For equipment that is not permanently installed, there's not much of an issue with homebrew, as far as the code goes, because the code doesn't deal with what's inside the equipment. For a lot of low-voltage equipment, the code rules are fairly easy to meet, as well, as long as the equipment is supplied by a listed power source of the appropriate type.

The problem arises with permanent installations, where the scope of the code and local regulations is ever increasing. Such things as solar panel installations, standby generators, personal computers, and home LANs all have received increased attention in local codes.

Station Power

Amateur Radio stations generally require a 120 V ac power source, which is then converted to the proper ac or dc levels required for the station equipment. In residential systems, voltages from 110 V through 125 V are treated equivalently, as are those from 220 V through 250 V. Amateurs setting up a station in a light industrial or office environment may encounter 208 V line voltage. Most power supplies operate over these ranges, but it's a good idea to measure the voltage range at your station. (The measured voltage usually varies by hour, day, season, and location.)

Modern solid-state rigs often operate from dc power, provided by a suitable dc power supply, perhaps including battery backups. Sometimes, the dc power supply is part of the rig (as in a 50 V power supply for a solid-state linear). Other times, your shack might have a 12 V (13.8 V) bus that supplies many devices. Just because it's low voltage doesn't mean that there aren't aspects of the system that raise safety concerns. A 15 A, 12 V power supply can start a fire as easily as a 15 A, 120 V branch circuit.

International Power Standards

The power grid of the United States and Canada uses a frequency of 60 Hz and the voltage at ac power outlets is 120 V. This is also the case in other North American countries. If you travel, though, you'll encounter 220 V and 50 Hz with quite an array of plugs and sockets and color codes. If you are planning on taking Amateur Radio equipment with you on a vacation or DXpedition, you'll need to be prepared with the proper adapters and/or transformers to operate your equipment.

Connecting and Disconnecting Power

Something that is sometimes overlooked is that you need to have a way to safely disconnect all power to everything in the shack. This includes not only the ac power, but also battery banks, solar panels, and uninterruptible power supplies (UPS). Most hams won't have the luxury of a dedicated room with a dedicated power feed and the "big red switch" on the wall, so you'll have several switches and cords that would need to be disconnected.

The realities of today's shacks, with computers, multiple wall transformers ("wall-warts"), network interfaces, and the radio equipment itself makes this tricky to do. One convenient means is a switched outlet strip, as used for computer equipment, if you have a limited number of devices. If you need more switched outlets, you can control multiple low-voltage controlled switched outlets from a common source. Or you can build or buy a portable power distribution box similar to those used on construction sites or stage sets; they are basically a portable subpanel with individual circuit breakers (or GFCIs, discussed later) for each receptacle, and fed by a suitable cord or extension cord. No matter what scheme you use, however, it's important that it be labeled so that someone else will know what to do to turn off the power.

AC Line Power

If your station is located in a room with

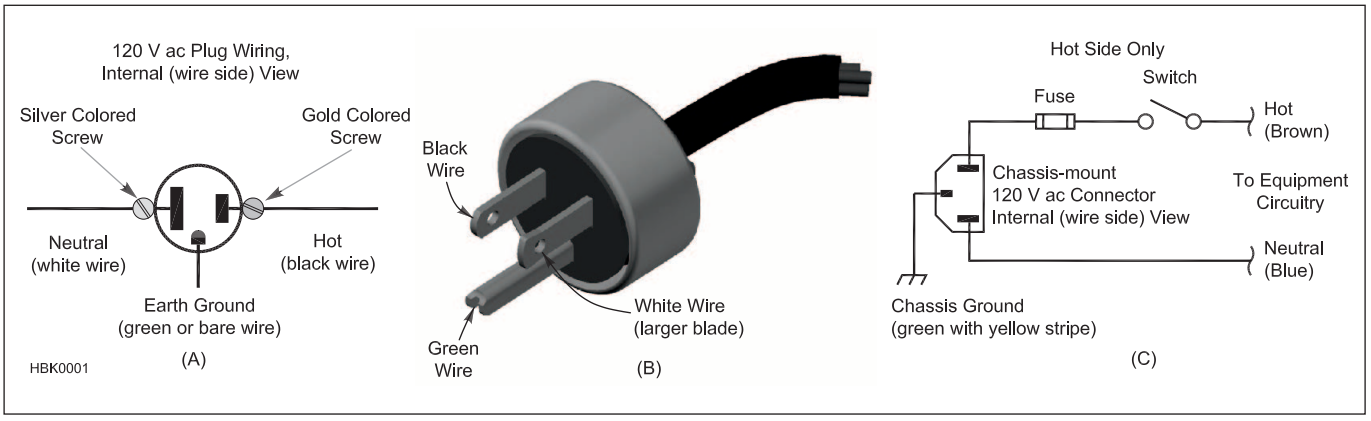


Figure 3 — 120 V ac plug wiring as viewed from the wire side (A) and viewed from the blade side (B). Wiring for an IEC type chassis connector is shown at C. Actual wire colors may vary.

electrical outlets, you're in luck. If your station is located in the basement, an attic or other area without a convenient 120 V source, you may need to have a new line run to your operating position.

Stations with high-power amplifiers should have a 240 V ac power source in addition to the 120 V supply. Some amplifiers may be powered from 120 V, but they require current levels that may exceed the limits of standard house wiring. To avoid overloading the circuit and to reduce household light dimming or blinking when the amplifier is in use, and for the best possible voltage regulation in the equipment, it is advisable to install a separate 240 or 120 V line with an appropriate current rating if you use an amplifier.

The usual circuits feeding household outlets are rated at 15 or 20 A. This may or may not be enough current to power your station. To determine how much current your station requires, check the VA (volt-amp) ratings for each piece of gear. Usually, the manufacturer will specify the required current at 120 V; if the power consumption is rated in watts, divide that rating by 120 V to get amperes. Modern switching power supplies draw more current as the line voltage drops, so if your line voltage is markedly lower than 120 V, you need to take that into account.

Note that the code requires you to use the "nameplate" current, even if you've measured the actual current, and it's less. If the total current required is near 80% of the circuit's rating (12 A on a 15 A circuit or 16 A on a 20 A circuit), you need to install another circuit. Keep in mind that other rooms may be powered from the same branch of the electrical system, so the power consumption of any equipment connected to other outlets on the branch must be taken into account. If you would like to measure just how much power your equipment consumes, the inexpensive Kill-A-Watt meters by P3 International (**www.p3international.com**) measure volts, amps, VA, and power factor.

If you decide to install a separate 120 V line or a 240 V line, consult the local requirements as discussed earlier. In some areas, a licensed electrician must perform this work. Others may require a special building permit. Even if you are allowed to do the work yourself, it might need inspection by a licensed electrician. Go through the system and get the necessary permits and inspections! Faulty wiring can destroy your possessions and take away your loved ones. Many fire insurance policies are void if there is unapproved wiring in the structure.

If you decide to do the job yourself, work closely with local building officials. Most home-improvement centers sell books to guide do-it-yourself wiring projects. If you have any doubts about doing the work yourself, get a licensed electrician to do the installation.

Three-wire 120 V Power Cords

Most metal-cased electrical tools and appliances are equipped with three-conductor power cords. Two of the conductors carry power to the device, while the third conductor is connected to the case or frame. Figure 3 shows two commonly used connectors.

When both plug and receptacle are properly wired, the three-contact polarized plug bonds the equipment to the system ground. If an internal short from line to case occurs, the "ground" pin carries the fault current and hopefully has a low enough impedance to trip the branch circuit breaker or blow the fuse in the device. A second reason for grounding the case is to reduce the possibility of shock for a user simultaneously connected to ground and the device. In modern practice, however, shock prevention is often done with GFCI circuit breakers, as described below. These devices trip at a much lower level, or as the result of an imbalance between neutral and ground, and are more reliable. Most commercially manufactured test equipment and ac-operated amateur equipment is supplied with three-wire cords.

It's a good idea to check for continuity from case to ground pin, particularly on used equipment, where the ground connection might have been broken or modified by the previous owner. If there is no continuity, have the equipment repaired before use.

Use such equipment only with properly installed three-wire outlets. If your house does not have such outlets, either consult a local electrician to learn about safe alternatives or have a professional review information you might obtain from online or other sources.

Equipment with plastic cases is considered "double insulated" and fed with a two-wire cord. Such equipment is safe because both conductors are insulated from the user by two layers. Nonetheless, there is still a hazard if, say, a double insulated drill were used to drill an improperly grounded case of a transmitter that was still plugged in. Remember, all insulation is prey to age, damage, and wear that may erode its initial protection.

Transfer Switches and Generators

More hams are adding standby generators and using alternate power sources such as solar panels or wind turbines, not as standalone systems like at Field Day, but interconnected with their home electrical system. These present some potential safety problems, such as preventing the local generator from "back-feeding" the utility's system during a power failure, and the fact that a solar panel puts out power whenever there is light falling on it.

For generators, the recommended approach is to use a *transfer switch*, which is a multipole switch that connects a selection of the house's circuits to the generator, rather than the utility power. The NEC and local regulations should be consulted for transfer switch selection and connection. The required wiring practices for permanently installed (stationary) generators are different from those for portable generators. Some issues that need to be considered are whether the neutral should be switched (many transfer switches do not switch the neutral, only the hot wire), and how the generator chassis is bonded to the building's grounding/bonding system. Most proper transfer switches are of the ON-OFF-ON configuration, with a mechanical interlock that prevents directly switching from one source to the other in a single operation.

The most dangerous thing to do with a generator is to use a so-called "suicide cord" with a male plug at each end: one end plugged into the generator's output receptacle and the other plugged into a convenient receptacle in the home. This is illegal, and at any rate should be avoided because of the inherent danger of having exposed, live contacts and the ease of overloading the circuit being fed.

Back-feeding your home's power panel should *never* be done. Connect appliances to the generator directly with extension cords.

Ground-Fault and Arc-Fault Circuit Interrupters

GFCIs are devices that can be used with common 120 V household circuits to reduce the chance of electrocution when the path of current flow leaves the branch circuit (say, through a person's body to another branch or ground). An AFCI is similar in that it monitors current to watch for a fault condition. Instead of current imbalances, the AFCI detects patterns of current that indicate an arc — one of the leading causes of home fires. The AFCI is not supposed to trip because of "normal" arcs that occur when a switch is opened or a plug is removed.

The NEC requires GFCI outlets in all wet or potentially wet locations, such as bathrooms, kitchens, and any outdoor outlet with ground-level access, garages and unfinished basements. Any area with bare concrete floors or concrete masonry walls should be GFCI equipped. GFCIs are available as portable units, duplex outlets and as individual circuit breakers. Some early units may have been sensitive to RF radiation but this problem appears to have been solved. Ham radio shacks in potentially wet areas (basements, out buildings) should be GFCI equipped. Figure 4 is a simplified diagram of a GFCI.

Older equipment with capacitors in the 0.01 µF to 0.1 µF range connected between line inputs and chassis as an EMI filter (or that has been modified with bypass capacitors) will often cause a GFCI to trip, because of the leakage current through the capacitor. The must-trip current is 5 mA, but many GFCI strip at lower levels. At 60 Hz, a 0.01 µF capacitor has an impedance of about 265 kΩ, so there could be a leakage current of about 0.5 mA from the 120 V line. If you had several pieces of equipment with such capacitors, the leakage current will trip the GFCI.

Some early GFCI breakers were susceptible to RFI, but as the technology has improved, fewer and fewer such reports have been received. While it is possible to add filtering or RF suppression to the breaker wiring, a simpler and less expensive solution is to simply replace the GFCI breaker with a new unit less susceptible to RF. For more information on RFI and GFCI/AFCI devices, check the ARRL web page **www.arrl.org/gfci-devices**.

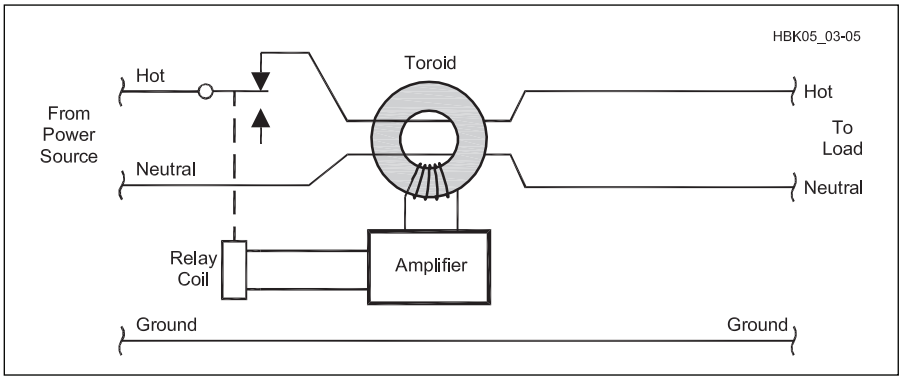
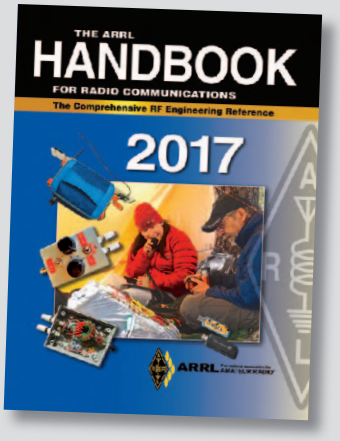


Figure 4 — Simplified diagram of a 120 V ac ground fault circuit interrupter (GFCI). When a stray current flows from the load (or outlet) side to ground, the toroidal current becomes unbalanced allowing detection, amplification and relay actuation to immediately cut off power to the load (and to the stray path!) GFCI units require a manual reset after tripping. GFCIs are required in wet locations (near kitchen sinks, in garages, in outdoor circuits, and for construction work.) They are available as portable units or combined with over-current circuit breakers for installation in entrance panels.

Would you like to know more?

Pick up your copy of the *2017 ARRL Handbook* at your favorite dealer, or order online at **www.arrl.org/shop**.



Safety First!

Part 2 — Grounding.

This article is the second of a multipart series on safety, excerpted from the* 2017 ARRL Handbook*. Part 1 can be found in the November 2016 issue, on pages 39 – 43.

As hams, we are concerned with at least four kinds of things called "ground," even if they really aren't ground in the sense of connection to the Earth. These are easily confused because we call each of them "ground." They are:

1) Electrical safety ground (bonding)

2) RF return (antenna ground)

3) Common reference potential (chassis ground)

4) Lightning and transient dissipation ground

Electrical Safety Ground (Bonding)

Power-line ground is required by building codes to ensure the safety of life and property surrounding electrical systems. The National Electrical Code (NEC) requires that all grounds be *bonded* together; this is a very important safety feature, as well as an NEC requirement.

The usual term one sees for the "third prong" or "green-wire ground," is the *electrical safety ground*. The purpose of the third, non-load current carrying wire is to provide a path to ensure that the overcurrent protection will trip in the event of a line-to-case short circuit in a piece of equipment. This could either be the fuse or circuit breaker back at the main panel, or the fuse inside the equipment itself.

There is a secondary purpose for shock reduction: The conductive case of the equipment is required to be connected to the bonding system, which is also connected to Earth ground at the service entrance, so someone who is connected to "Earth" (for example, standing in bare feet on a conductive floor) that touches the case won't get shocked.

An effective safety ground system is necessary for every amateur station, and the code requires that all the "grounds" be bonded together. If you have equipment at the base of a tower, for example, you need to provide a separate bonding conductor to connect the chassis and cases at the tower to the bonding system in the shack. The electrical safety ground provides a common reference potential for all parts of the ac system. Unfortunately, an effective bonding conductor at 60 Hz may present very high impedance at RF because of the inductance, or worse yet, wind up being an excellent antenna that picks up the signals radiated by your antenna.

RF Ground

RF ground is the term usually used to refer to things like equipment enclosures. It stems from days gone by when the long-wire antenna was king. At low enough frequencies, a wire from the chassis or antenna tuner in the shack to a ground rod pounded in outside the window had low RF impedance. The RF voltage difference between the chassis and "Earth ground" was small. And even if there were small potentials, the surrounding circuitry was relatively insensitive to them.

Today, though, we have a lot of circuits that are sensitive to interfering signals at millivolt levels, such as audio signals to and from computer sound cards. The summary is that we shouldn't be using the equipment enclosures or shielding conductors as part of the RF circuit.

Instead, we design our systems to create a common reference potential, called the "reference plane," and we endeavor to keep equipment connected to the reference plane at a common potential. This minimizes RF current that would flow between pieces of equipment.

Some think that RF grounds should be isolated from the safety ground system — *that is not true! All grounds, including safety, RF, lightning protection and commercial communications, must be bonded together in order to protect life and property.* The electrical code still requires that antenna grounds be interconnected (bonded) to the other "grounds" in the system, although that connection can have an RF choke. Remember that the focus of the electrical code bonding requirement is safety in the event of a short to a power distribution line or other transient.

Common Reference Potential (Chassis Ground)

For decades, amateurs have been advised to bond all equipment cabinets to an RF ground located near the station. That's a good idea, but it's not easily achieved. Even a few meters of wire can have an impedance of hundreds of ohms (1 μH/meter = 88 Ω/meter at 14 MHz). A better approach is to connect the chassis together in a well-organized fashion to ensure that the chassis-to-chassis connections don't carry any RF current at all, as in Figure 1.

Lightning Dissipation Ground

Lightning dissipation ground is concerned with conducting currents to the surrounding Earth. There are distinct similarities between lightning dissipation ground systems and a good ground system for a vertical antenna. Since the lightning impulse has RF components around 1 MHz, it is an RF signal, and low inductance is needed, as well as low resistance.

The difference is that an antenna ground plane may handle perhaps a few tens of amps, while the lightning ground needs to handle a peak current of tens of kiloamperes.

A typical lightning stroke is a pulse with a rise time of a few microseconds, a peak current of 20 – 30 kA, and a fall time of 50 μs.

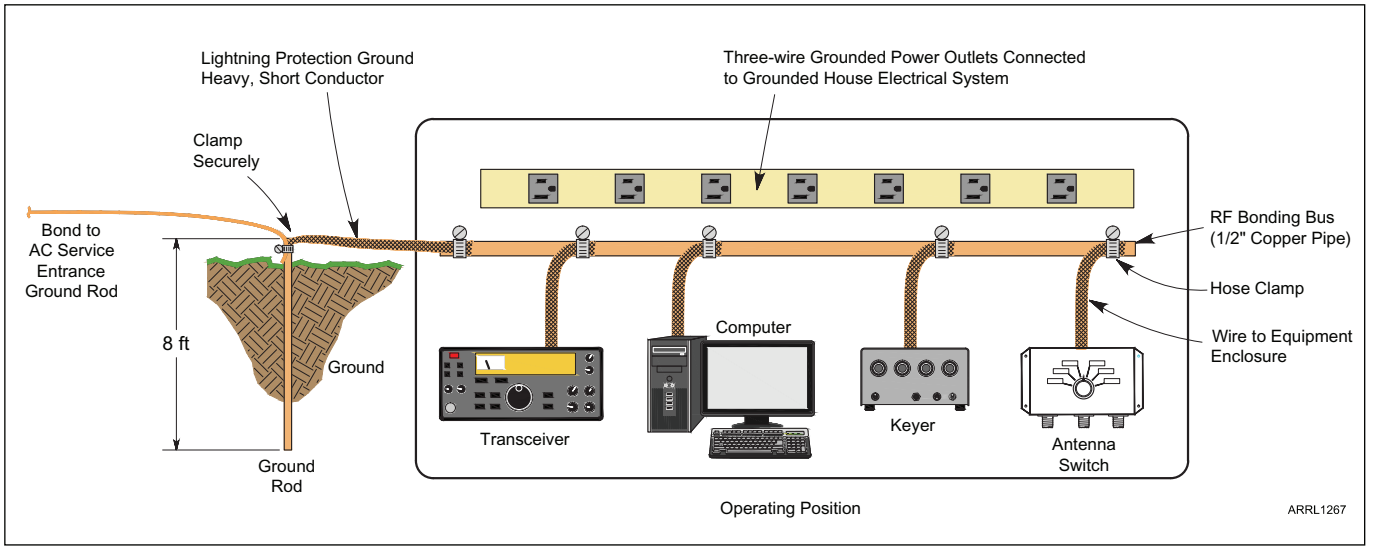


Figure 1 — An RF bonding bus connects all of the equipment enclosures together to keep them at the same RF voltage. If the bus is connected to a lightning protection ground, use a heavy conductor, fastened securely. All ground rods must be bonded together and to the residence's ac service entry ground rod. The RF bonding bus should also be connected to the ac safety ground.

The average current is not all that high (a few hundred amps), so the conductor size needed to carry the current without melting is surprisingly small.

However, large conductors are used in lightning grounds for other reasons: to reduce inductance, to handle the mechanical forces from the magnetic fields, and for ruggedness to prevent inadvertent breakage. A large diameter wire, or even better, a wide flat strap, has lower inductance. The voltage along a wire is proportional to the change in current and the inductance:

$$|V| = L\frac{di}{dt}$$

where

di/dt = rate of change in current, about 20kA/2μs for lightning, or 10^9 A/s, and

L = the inductance.

Consider a connection box on a tower that contains some circuitry terminating a control cable from the shack, appropriately protected internally with overvoltage protection. If the connection from the box to ground is high inductance, the lightning transient will raise the box potential (relative to the wiring coming from the shack), possibly beyond the point where the transient suppression in the box can handle it. Lowering the inductance of the connection to ground reduces the potential.

The other reason for large conductors on lightning grounds is to withstand the very high mechanical forces from the high currents. This is also the reason behind the recommendation that lightning conductors be run directly, with minimal bends, large radii for bends that are needed, and certainly no loops. A wire with 20,000 A has a powerful magnetic field surrounding it, and if current is flowing in multiple wires that are close to each other, the forces pushing the wires together or apart can actually break the conductors or deform them permanently.

Grounding Methods

Earth ground usually takes one of several forms, all identified in the NEC and NFPA 780. The preferred Earth ground, both as required in the NEC, and verified with years of testing in the field, is a concrete-encased grounding electrode (CEGR), also known as a *Ufer ground*, after Herb Ufer, who invented it as a way to provide grounding for military installations in dry areas where ground rods are ineffective. The CEGR can take many forms, but the essential aspect is that a suitable conductor at least 20 feet long is encased in concrete that is buried in the ground. The conductor can be a copper wire (#8 AWG at least 20 feet long) or the reinforcing bars (rebar) in the concrete, often the foundation footing for the building. The connection to the rebar is either with a stub of the rebar protruding through the concrete's top surface, or the copper wire extending through the concrete. There are other variations of the CEGR described in the NEC and in the electrical literature, but they're all functionally the same: a long conductor embedded in a big piece of concrete.

The electrode works because the concrete has a huge contact area with the surrounding soil, providing very low impedance and, what's also important, a low current density, so that localized heating doesn't occur. Concrete tends to absorb water, so it is also less susceptible to problems with the soil drying out around a traditional ground rod.

Ground rods are a traditional approach to making a suitable ground connection and are appropriate as supplemental grounds, say at the base of a tower, or as part of an overall grounding system. The best ground rods to use are those available from an electrical supply house. The code requires that at least 8 feet of the rod be in contact with the soil, so if the rod sticks out of the ground, it must be longer than 8 feet (10 feet is standard). The rod doesn't have to be vertical, and can be driven at an angle if there is a rock or hard layer, or even buried lying sideways in a suitable trench, although this is a compromise installation. Suitable rods are generally 10 feet long and made from steel with a heavy copper plating. Do not depend on shorter, thinly plated rods sold by some home electronics suppliers, as they can quickly rust and soon become worthless.

If multiple ground rods are installed, they should be spaced by at least half the length of the rod, or the effectiveness is compro-

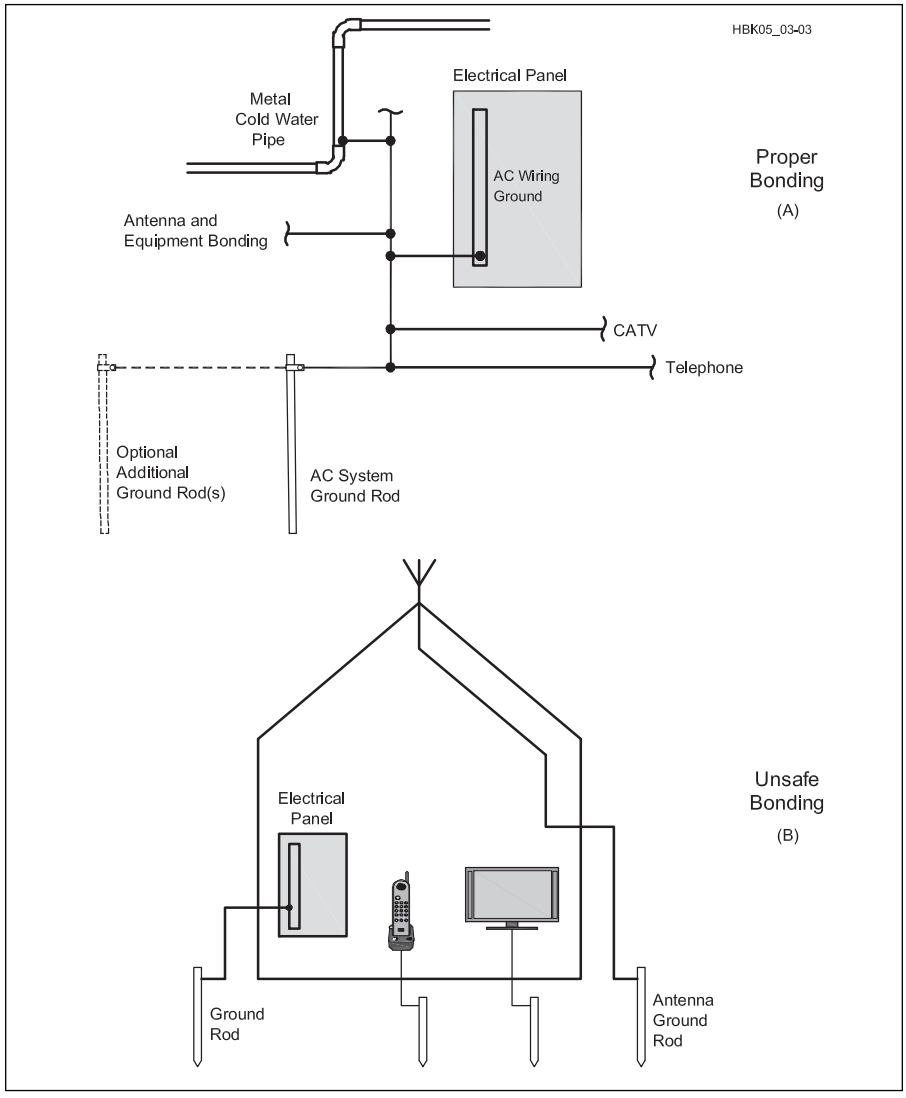


Figure 2 — At A, proper bonding of all grounds to electrical service panel. The installation shown at B is unsafe — the separate grounds are not bonded. This could result in a serious accident or electrical fire.

mised. IEEE Std 142, IEEE Std 1100, and other references have tables to give effective ground resistances for various configurations of multiple rods.

Once the ground rods are installed, they must be connected with either an exothermic weld (such as CadWeld) or with a listed pressure clamp. The exothermic weld is preferred, because it doesn't require annual inspection like a clamp does. Some installers use brazing to attach the wiring to the ground rods. Although this is not permitted for a primary ground, it is acceptable for secondary or redundant grounds. Soft solder (tin-lead, as used in plumbing or electrical work) should never be used for grounding conductors because it gets brittle with temperature cycling and can melt out if a current surge (as from a lightning strike) heats the conductor. Soft solder is specifically prohibited in the code.

Building cold-water supply systems were used as station grounds in years past, but this is no longer recommended or even permitted in some jurisdictions, because of increased used of plastic plumbing both inside and outside houses, and concerns about stray currents causing pipe corrosion. If you do use the cold-water line, perhaps because it is an existing grounding electrode, it must be bonded to the electrical system ground, typically at the service entrance panel.

Ground Conductors

The code is quite specific as to the types of conductors that can be used for bonding the various parts of the system together. Grounding conductors may be made from copper, aluminum, copper-clad steel, bronze, or similar corrosion-resistant materials. Note that the sizes of the conductors required are based largely on mechanical strength considerations (to ensure that the wire isn't broken accidentally) rather than electrical resistance. Insulation is not required. The "protective grounding conductor" (main conductor running to the ground rod) must be as large as the antenna lead-in, but not smaller than #10 AWG. The grounding conductor (used to bond equipment chassis together) must be at least #14 AWG. There is a "unified" grounding electrode requirement — it is necessary to bond *all* grounds to the electric service entrance ground. All utilities, antennas, and any separate grounding rods used must be bonded together. Figure 2 shows correct (A) and incorrect (B) ways to bond ground rods. For additional information on good grounding practices, the IEEE "Emerald Book" (IEEE STD 1100-2005) is a good reference. It is available through libraries.

Additionally, the NEC covers safety inside the station. All conductors inside the building must be at least 4 inches away from conductors of any lighting or signaling circuit except when they are separated from other conductors by conduit or insulator. Other code requirements include enclosing transmitters in metal cabinets that are bonded to the grounding system. Of course, conductive handles and knobs must be grounded as well.

Would you like to know more?

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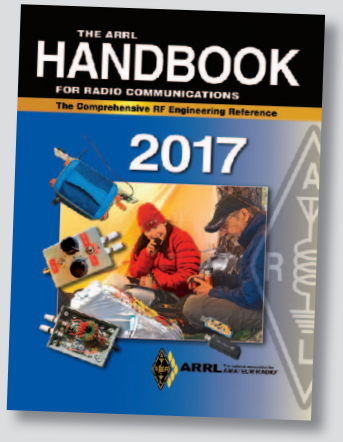

Safety First!

Part 3 — Climbing Safety.

This article is the third of a multi-part series on safety excerpted from the 2017 edition of* The ARRL Handbook. *Part 1 can be found in the November 2016 issue on pages 39 – 43. Part 2 can be found in the December 2016 issue on pages 39 – 41.

Tower climbing is a potentially dangerous activity, so you'll need to use the proper safety equipment and techniques. OSHA, the Federal Occupational Safety and Health Administration, publishes rules for workplace safety. Although amateurs are not bound by those rules, you'll be much better off if you follow them. The equipment and techniques you use are up to you.

Safety Awareness and Preparation

One of the most important aspects of safety is having the knowledge and awareness to do a job safely and efficiently. You must have the mental ability to climb and work at altitude while constantly rethinking all connections, techniques, and safety factors. Safely climbing and working on towers is 90% mental. Mental preparedness is something that must be learned. This is an occasion where there is no substitute for experience. The biggest obstacle for anyone is making the mental adjustment. Properly installed towers are inherently safe and accidents are relatively rare.

You should also check your safety equipment every time before you use it. Inspect it for any nicks or cuts to your belt and safety strap. Professional tower workers are required to check their safety equipment every day, and you should check yours before each use.

One of the most important lessons for tower climbing is that you have four points of attachment and security — two hands and two feet. When climbing, move only one point at a time. That leaves you with three points of contact and a wide margin of safety if you ever need it. This is in addition to having your fall arrest lanyard connected at all times.

Another recommended technique is to always do everything the same way every time. That is, always wear your positioning lanyard on the same D-ring and always connect it in the same way. Always look at your belt D-ring while clipping in with your safety strap. This way, you'll always confirm that you're securely belted in. Always look!

Personal Safety Equipment

The most important pieces of safety equipment are the fall arrest harness (FAH) you wear and the accompanying lanyards that attach to it (see Figure 1). The FAH has leg loops

(A) (B)

Figure 1 — (A) The well-dressed tower climber. Note the waist D-rings for positioning lanyard attachment as well as the suspenders and leg loops. At (B) is an adjustable positioning lanyard. The climber also has workboots, gloves, safety glasses, and a hard hat.

and suspenders to help spread the fall forces over more of your body and has the ability to hold you in a natural position with your arms and legs hanging below you where you're able to breathe normally.

Two or more lanyards are used. One is the positioning lanyard (see Figure 2). That is, it holds you in working position and attaches to the D-rings at your waist. They can be adjustable or fixed and are made from different materials, such as nylon rope, steel chain, or special synthetic materials. An adjustable positioning lanyard will adjust to almost any situation, whereas a fixed-length one is typically either too long or too short. A rope lanyard is the least expensive.

Leather safety equipment was outlawed some years ago by OSHA, so don't use it. This includes the old-fashioned safety belt that was used for years but offers no fall arrest capability. If you drop down while wearing a safety belt, your body weight can cause it to rise up from your waist to your ribcage, where it will immobilize your diaphragm and suffocate you. On the other hand, you can use a safety belt for positioning when it's worn over an FAH. Just don't depend on it to catch you in case of a fall.

The other lanyard is the fall arrest lanyard, shown in Figure 3, which attaches to a D-ring between your shoulder blades. The other end attaches to the tower above the work position and catches you in case of a fall. The simplest is a 6-foot rope lanyard, which is inexpensive but doesn't offer any shock absorption. There are also shock-absorbing varieties that typically have bar-tacked stitches that pull apart under force to decelerate you. Don't cut corners on buying or using safety equipment; you bet your life on it every time you use it!

OSHA rules and good common sense say you should be attached to the tower 100% of the time. You can do this several ways. One is to attach the fall arrest lanyard above you and climb up to it. Use your positioning lanyard to hold you while you detach it and move it up again. Repeat as necessary. Another option is to use a pair of fall arrest lanyards, attaching one then the other as you climb the tower.

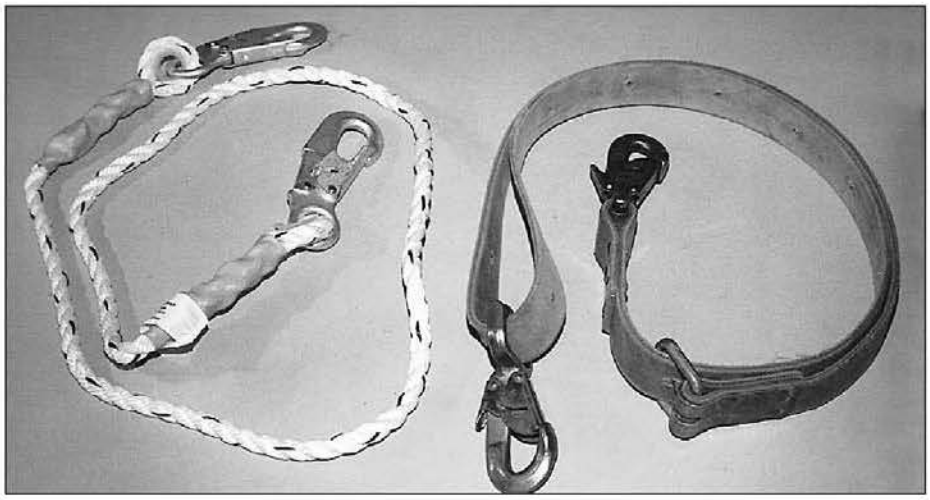

Figure 2 — A fixed-length rope positioning lanyard on the left and a versatile adjustable lanyard on the right.

Figure 3 — The fall arrest lanyard is above the climber so that the climber can climb up to it. The fall-arrest and positioning lanyards are then "leapfrogged" so that the climber remains attached to the tower 100 percent of the time.

Boots should be leather with a steel or fiberglass shank. Diagonal bracing on Rohn 25G is only a 5/16-inch rod — spending all day standing on that small step will take a toll on your feet. The stiff shank will support your weight and protect your feet; tennis shoes will not. Leather boots are mandatory on towers like Rohn BX that have sharp X-cross braces. Your feet are always on a slant and that is hard on them.

A hard hat and safety goggles are highly recommended. Just make sure they are ANSI or OSHA approved and that you and your crew wear them. As you'll be looking up and down a lot, a chin strap is essential to keep the hard hat from falling off.

If you do a lot of tower work, your hands will take a beating. Gloves are essential — keep several spare pairs for ground crew members who show up without them. Cotton gloves are fine for gardening, but not for tower work; they don't provide enough friction for climbing or working with a haul rope. Leather gloves are the only kind to use; either full leather or

leather-palmed are fine. The softer the gloves, the more useful they'll be. Stiff leather construction gloves are fine for the ground crew, but pigskin and other soft leathers are better for the climber, because you can thread a nut or do just about any other delicate job with these gloves on.

Safety Tips

1) Don't climb with anything in your hands; attach an item to your safety belt if you must climb with it, or have your ground crew send it up to you in a bucket.

2) Don't put any hardware in your mouth; it can easily be swallowed.

3) Remove any rings and/or neck chains; they can get hooked on things.

4) Be on the lookout for bees, wasps, and their nests. If you do run into a hornet, wasp, or other stinging insect, use Adolph's Meat Tenderizer on the sting — it contains the enzyme papain, which neutralizes the venom. Keep a small jar in your tool kit.

5) Don't climb when tired; that's when most accidents occur.

6) Don't try to lift anything by yourself; one person on a tower has very little leverage or strength. Let the ground crew use their strength; save yours for when you really need it.

7) If a procedure doesn't work, assess the situation and re-rig, if necessary, before trying again.

8) Never climb a tower that is rusted, or otherwise has poor mechanical integrity.

Ground Crew Safety

The climber on the tower is the boss. Before tower work starts, have a safety meeting with the ground crew. Explain what is going to be done and how to do it, as well as introducing them to any piece of hardware with which they may not be familiar (for example, carabiners, slings, or come-along winches).

As part of the ground crew, there are a few rules to follow:

1) The climber on the tower is in charge.

2) Don't do anything unless directed by the climber in charge on the tower. This includes handling ropes, tidying up, moving hardware, and so on.

3) If not using radios to communicate, when talking to the climber on the tower, look up and talk directly to him or her in a loud voice. The ambient noise level is higher up on the tower because of traffic, wind, and nearby equipment.

4) Communicate with the climber on the tower. Let him or her know when you're ready, if you're standing by, or if there is a delay. Advise the climber when lunch is ready!

Would you like to know more?

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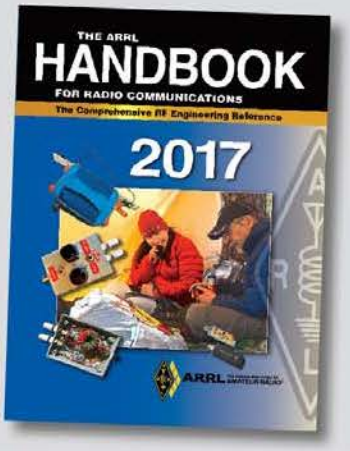

Strays

The Bloomington ARC Issues a Challenge

The Bloomington Amateur Radio Club (BARC) in Indiana challenges clubs to beat its effort to help ARISS (Amateur Radio on the International Space Station) replace its failed radio. After learning of the failure, the club voted to give $100 to ARISS, then three members quickly matched that amount with their own checks, and others chipped in to make a total of $600! BARC officers and others are (from left, front row) Vice President Tim Day, AC9ML; ARRL ARISS Delegate Rosalie White, K1STO; President Jimmy Merry, KC9RPX; Board Member Richard Phillips, WA9MTH; (from left, back row) Board Member Ray Stevens, KB9LGS; ARRL Indiana Section Manager Brent Walls, N9BA; Secretary Bill Wootton, KC9ACL; Public Information Officer Carol Emmons, KD9BSJ, and Board Member Bill Evans, N9SYI. [Rob Hamros, KB9RNB, photo]